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FORMING OF INTEGRAL RIBS BY COLD PRESS-EXTRUSION TECHNIQUES

by P. H. SCHUERER AND P. R. BRADIE
Manufacturing Engineering Laboratory

In cooperation with the Technology Utilization Office

NASA

George C. Marshall Space Flight Center, Huntsville, Alabama

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P. H. Schuerer
P. R. Bradie

George C. Marshall Space Flight Center
Huntsville, Alabama

ABSTRACT

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This report covers the theory involved, the actual techniques employed, a general description of equipment and materials used, and the initial results of a pilot operation to prove the feasibility of forming fully developed integral ribs by means of cold press-extrusion techniques. The panels so formed exhibit properties equivalent to those of the desired alloy and temper. The lines of grain flow are smooth and uninterrupted, so it is expected that ultimate strength, fatigue resistance, and reliability should be superior to "waffled" panels formed by such conventional methods as chemical or mechanical milling.

A great amount of research and development work still needs to be done in forming full size panels with rib spacing up to twenty-seven inches. A major area of difficulty will be the control of skin thickness (panel flats) where "waffled" areas vary in size. Also, further work is required to optimize the sequence of operations in forming "waffled" panels.

Author

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METHODS DEVELOPMENT BRANCH
MANUFACTURING ENGINEERING LABORATORY

FOREWORD

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This document is in direct support of the policy that all new technology gained through the various research and development programs performed by and for the National Aeronautics and Space Administration should be made available to the people. The method of forming of intergral ribs by cold press-extrusion techniques described herein is a direct result of techniques developed by a NASA contractor for the Manufacturing Engineering Laboratory of the George C. Marshall Space Flight Center.

Additional information may be obtained from:

The Chief, Technology Utilization Office
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SUMMARY

ABST

An experimental, scale-size, waffle panel with integral ribs was incrementally formed by a cold press-extrusion technique. Overall panel finish was good, with no evidence of severe galling or roping. Some irregularities in rib width and skin thickness were evident. Grain flow throughout the panel appeared to be equivalent to that obtained by the best commercial forging practice. Mechanical properties of specimens taken from the test panel compare favorably with properties expected from 2219-T81 alloy.

Author

SECTION I. INTRODUCTION

The conventional method of producing skin panels having integral ribs is by machining away or "hogging out" metal in rectangular or longitudinal patterns from areas on one surface of the panel. This operation produces a series of integral ribs in any desired pattern, e. g., longitudinal or "waffled", but requires a very accurate and expensive piece of machining equipment, a considerable amount of time, and results in the loss of up to 90 per cent of the starting raw material in the form of machining chips. This loss of material alone makes it highly desirable that some other method of producing panels having integral ribs be developed.

Production of metal parts by extrusion is a method which utilizes a maximum percentage of starting material and minimizes the quantity lost in placing material in the desired location and configuration. Cold press-extrusion of relatively thin aluminum alloy plate into a panel having a waffle pattern of integral ribs would be a very efficient and satisfactory method of producing such panels.

A study to determine the feasibility of forming integrally ribbed waffle sections incrementally by cold press-extrusion was performed by Lyon, Inc., Detroit, Michigan, under Contract NAS8-5163. An evaluation of two finished panels produced during this study was made by the Materials Division, Propulsion and Vehicle Engineering Laboratory, George C. Marshall Space Flight Center.

This report, prepared by the Missile and Space Support Division, Hayes International Corporation, is a compilation of information developed during the course of the feasibility study by Lyon and the panel evaluation by P&VE.

SECTION II. METHOD OF FORMING

A. GENERAL THEORY

All metals become plastic when subjected to sufficient stress at a given temperature. The metal tends to reduce the stress by flowing from high stress areas to low stress areas. By channeling this flow into desired areas, shapes may be formed. In this specific application, punches spaced in a grid pattern are placed on an aluminum sheet. When sufficient pressure is applied to any one punch, the aluminum flows from underneath in waves dictated by the contour of the punch. This displaced metal tends to increase the thickness of the surrounding area, which raises the stress level under the surrounding punches. The path of least resistance is to fill the voids between the punches, resulting in a raised rib shaped to the between-punch space configuration.

B. SUBSCALE MODELING

The primary objective of this work was to determine the feasibility of forming integrally ribbed waffle sections incrementally by a cold extrusion technique. The technique is to be applicable to waffle skin segments up to 120 inches wide, 315 inches long, and having rib spacings up to 27 inches rib-to-rib. To this end, subscale tooling was designed and built to produce an experimental panel as shown in MSFC Drawing SK-120 in Figure 1.

The initial step was the extrusion of a lead panel with flat punches to determine the precise flow pattern. An extrusion of 2219-0 aluminum was then attempted with flat punches to determine tonnage relationships for relative positions and sizes of the individual punches. Figure 2 shows the initial lead panel extrusion.

It was realized that the working surfaces of the flat punches would require some degree of contouring to obtain uniform metal flow. A model of a flat punch was constructed out of Lucite, and a panel of modeling clay was extruded to assure duplication of the flow pattern achieved with lead sheet. Results were not definitive due to inadequate flow resistance of the clay. A soft wax was found that showed flow characteristics suitable for indicating pressure gradients. This medium was employed for testing extrusion characteristics of various contoured punches.

When the punch contours were considered satisfactory, they were transferred to the steel working punches. These in turn were tried by striking a lead panel with a crowned punch followed by a flat punch, giving fully formed ribs as shown in Figures 3 and 4.

C. FORMING SEQUENCE

The alloy blanks to be used are finish-machined to shape. A thin film of a newly developed chemical boundary lubricant (Cimcool) is applied to both sides of the blank prior to positioning in the lower die assembly. The punch faces are lubricated, and press operations begin with all 3 degree angle punches applied simultaneously to maximum tonnage. This seats the blank firmly and evenly into the lower die assembly without significant extrusion of the aluminum.

Actual extrusion begins by applying maximum tonnage to individual 3 degree punches selected by adjusting the position of the cam backup plates. After each operation, the punch faces and work piece are relubricated. At completion of this stage, the partially extruded panel is removed from the press and annealed. The 3 degree angle punches are removed and flat punches installed.

The annealed panel is repositioned in the lower die assembly and the extrusion process continues in much the same manner as with the contoured punches. The flat punches extrude aluminum, selectively distributed by the contoured punches, into ribs approximately 3/4-inch high. Fully developed 1 1/2-inch high ribs are formed by repeating the extrusion sequence of contoured and flat punches. The panel is annealed after each stage, and punch faces and panel are lubricated after each operation.

After the last extrusion operation, the panel is solution-treated by heating at 1000° F for 30 minutes and cold-water quenching within four seconds after removal from the furnace.

The panel is then given an additional 8 per cent cold reduction with flat punches, then aged for 24 hours at 325° F to obtain -T87 properties.

D. EXTRUSION PROBLEMS

1. Flow Control. The initial strike was made with a flat-faced punch on a lead sheet. Figure 2 shows clearly the lack of uniformity in the rib sections due to the uncontrolled flow of metal. It was also noted that excessive pressures were required to extrude an aluminum panel with such a flat punch on the initial strike.

By the use of a Lucite punch model and clay panel mounted in a Tinius-Olsen testing machine, it was found that an appreciable reduction in pressure could be gained through the use of a crowned punch with a 12 degree included angle (6 degree punch). A lead sheet was struck with a 6 degree punch and a good metal flow toward the rib sections was noted. Figure 3 shows the lead panel after being struck with the 6 degree punch. A restrike with the flat punches fully developed ribs with uniform height and thickness, Figure 4.

When a panel of 2219-0 alloy was processed with the crowned punches, inspection revealed that the outer surface of the panel in contact with the bottom die platen had developed pockets below the rib intersections as shown in Figure 5. The formation of these pockets resulted from the uneven pressures exerted by the tapered facets of the contoured punch. The center of the punch developed a high force concentration on the metal. The lack of confinement from the remainder of the punch face allowed the metal to flow upward as well as outward.

When the panel was restruck with the flat punches, the pockets were eliminated and the outer surface of the panel was again flat and smooth. However, the metal flowing into the pockets was no longer available to completely fill the rib sections, resulting in a lower rib height at the point of intersection, Figure 6. There was considerable improvement in rib uniformity compared with an extrusion produced by flat punches only.

2. Wave Action. One panel of unalloyed aluminum was extruded by alternating the use of crowned and flat punches a number of times. The rib height increased by increments with each cycle, but when the pockets were repeatedly formed and removed, a wave action was established across the flat area between ribs. This, in turn, produced folds in the metal at the lines where the ribs form a right angle with the inner panel surface. As the rib extruded upward, laminations were produced across the width of the rib.

Several combinations of flat and crowned punches were used within the die assembly, and various sequences of punch operation were tried on unalloyed blanks. The pocket formations were greatly reduced and the rib uniformity improved, with some slight degree of lamination persisting.

By employing a 3 degree crowned punch, pocket formations were almost completely eliminated, and laminations show as slight cracks in the rib fillet area.

3. Force Requirements. Estimates of applied tonnage are based solely on visual observation of the workpiece and a knowledge of die characteristics under full load. Using 6 degree contoured punches, approximately one-fourth of the available tonnage is dissipated by the non-working (holding) punches. Approximately 3750 tons are available to a single working punch. With flat punches, approximately half the available tonnage is dissipated by the non-working punches. In all instances, friction is considered negligible.

The 6 degree crowned punches caused pockets to form in the outer panel surface. To eliminate this problem, it was evident that the contoured punches would require an angle less than 6 degrees. It was found through subscale experimentation that the contour angle must be 3 degrees or less to avoid pocket formation. Since the force required for extrusion varies inversely with angle increase, the maximum allowable angle of 3 degrees was selected for the punch contour. Even with this contour, the final extrusion requires multiple passes and frequent annealing to achieve fully developed ribs.

4. Web Thickness Control. It is evident that where the rib-to-rib dimension varies, the punch face heights will also vary when the punch face angle is constant. A recommendation was made that more efficient extrusion would result if the angles on the contour punches were changed so all punch face heights were equal. The angles would be different for various punch dimensions and be determined by that height which subtends a 3 degree angle on the punch side having the least height. The subtended angles on the larger dimensions would then be smaller. Figure 7 gives an example of this.

However, in order to do this, either a larger press is required (more force on the flatter punches) or a greater number of passes with the flatter punches must be made.

SECTION III. EQUIPMENT AND MATERIALS USED

A. GENERAL

The work involved in the performance of this contract may be divided into three areas. First is subscale, low resistance models employed for engineering design. Second is the full scale, low resistance proof and test of tooling. Third is the full scale 2219 alloy extrusion process.

While it is realized that the finished panels are actually subscale models of the projected panels in size, it is convenient to deal with force and strength values, hence the usage of the term "full scale" when referring to the extrusion press and punches used.

The full size panels that will be "waffled" are expected to be 120 inches wide and 315 inches long. By using three rows of identical punches, each of which may be referred to as maintaining, working, or holding punches depending upon its function at any particular phase of the extrusion process, the panel areas may be developed a row at a time. After the completion of one row, the panel is indexed forward for the next row. Since only one punch actually works at a given time, the "working" punches adjacent serve as maintaining and holding punches. The limiting factor, then, is the width of the press. The force required is that necessary to extrude one flat area, regardless of panel size.

B. SUBSCALE MODELS

Lucite plastic models were made of the flat punches employed in the press. These allowed variations in punch contour to be easily made during the course of the design program.

Modeling clay was formed into models of the alloy panels and extruded with the Lucite punches.

By mounting the Lucite punch to the upper platen of a Tinius-Olsen tester, and placing the clay model on the lower platen, scaled data were derived on extrusion flow versus force for a given punch contour. This was related to metal flow, and was instrumental in developing the 6 degree crowned punch angle.

When "pocketing" was noted during full scale extrusion, it was realized that modeling clay did not have the same qualitative flow characteristics as aluminum. A soft wax did, however, and, used for panel models, was instrumental in developing the 3 degree crowned punch configuration.

C. FULLSCALE MODELS

Upon determination of punch configuration, steel punches were made and installed in the press. The punches were initially proofed by extruding lead panels. These panels also served to indicate the desired sequences for forming the 2219 alloy panels.

Unalloyed aluminum panels were also extruded to evaluate lubricants and sequencing of operations. These panels were used since unalloyed aluminum possesses a more rapid annealing response, is easier to extrude, and is less costly than 2219 alloy.

During the course of this full scale testing, it was noted that the initial configuration of the panels was responsible for difficulties in developing fully the rib in the thick-to-thin panel transition area. A redesign of the panel, shown in Figure 8, was a direct result of this testing.

D. PUNCH AND PRESS CONFIGURATIONS

Three types of punches were used in the course of this work; flat punches, 6 degree crowned punches, and 3 degree crowned punches.

The initial displacement of metal is caused by application of the crowned punch (initially 6 degrees, finalized at 3 degrees). The flat and ribs are shaped by a flat punch. Figures 9 and 10 show the configuration of the center punch, both 6 degree and 3 degree crown angles.

The upper press assembly holds the punches to be used. Individual punches are selected for maximum force application by means of cam backup plates.

The lower press assembly is shown, in general, by Figure 11. The ejector plate failed because of stress concentrations raised by the use of a single ejector pin. It was also found that the side rails were flexed by the transmission of force through the alloy panel.

SECTION IV. FORMING RESULTS

A. GENERAL

It was desired that the finished panel conform to MSFC Drawing SK-120, Figure 1. Irregularities in rib width and skin thickness were evident, and caused by flexure of the side rails which contain the blanks during extrusion.

The overall finish was good, with no evidences of severe galling or roping. The only evident machinery marks were those on the skin surface of the panel where irregularities caused by ejector plate failure were machined away. Figure 12 shows a completely extruded panel.

B. RIB FORMATION

The long rib in the thin panel area is fully developed. The long rib at the thick-to-thin transition is quite underdeveloped at, and approaching, the rib intersections. The short ribs are fully developed through the majority of the thin area, becoming underdeveloped as they approach intersection with the underdeveloped long rib.

Apparently the bulk of the rib metal in the transition zone came from the thin section, and insufficient metal was extruded from the thick panel section.

C. FLAT FORMATION

The flat areas show no indication of dishing, and with a panel showing an eight-inch grid, no indication of great thickness variance is evident. The general surface finish is good, with no evidences of irregularities, with the exception of cracks in the rib fillet areas.

D. GRAIN FLOW

1. General. The grain flow throughout the structure appears to be equivalent to best commercial forging practices, with no irregularities or discontinuities evident, with the exception of some fissures in the rib fillet area.

2. Fissures. The discontinuous cracks or fissures in the rib fillet areas appear to be folds or seams rather than cracks. Figure 13 shows a cross-section of the long rib in the panel transition area. A fissure can be seen in the thinner panel region at the rib fillet.

The area adjacent to the fissure contains voids that have the appearance of stress corrosion cracking, although stress corrosion is not substantiated. Figure 14 shows a 500X view of the fissure with a Keller's Etch.

This crack is in a particularly bad area since the panels (when used) will be loaded along the flat plane. The cracks would then serve as a focal point for stress concentration. Furthermore, -T87 gives the lowest tear strength of all the 2219 alloys.

3. Ribs, Fillets and Flats. As stated above, the grain flow is equivalent to best commercial forging practices.

The grain flow and structure through the lower third of the ribs is fine, with flow parallel to the worked surfaces. This condition extends to the top of the rib in a layer approximately .02 inch thick. Within the shell of work-reduced grain, the grain becomes an unaxial spongy mass, showing no grain stress. This is to be expected from the forming method; the top-most portion being "floated" on the stressed (extruded) material below.

Without grain reduction due to stressing, the frequent annealing allows the development of a large grain structure.

The flat sections show good grain size with flow lines parallel to the worked surfaces. Growth is a little finer than that of the unstressed rib sections.

The grain structure in the fillet areas is very close and fine, indicating maximum forming stresses occur there. The grain flow is excellent, being parallel to the worked surfaces (as expected) and extending sufficiently far into the matrix of the panel.

The grain under the ribs and at intersections is equivalent in structure to that of the flats; however, the flow lines do not remain parallel to the bottom surface. The general appearance is that of a relatively unstressed area, as shown in Figure 15, possibly analogous to a boundary layer in viscous fluid flow. The apparent lack of stressing would seem to preclude any propensity for stress corrosion or intergranular corrosion that may be encouraged by the oblique flow lines.

E. MECHANICAL PROPERTIES

The mechanical properties of the panel segment are presented in Table I. Specimens were removed from rib areas, thick (1/2 in.) panel areas, and thin (1/4 in.) panel areas both with and without ribs. The specimens removed from ribbed panel areas contained fissures in the rib fillets, as determined by dye penetrant inspection. Properties of all specimens compared favorably with values expected from 2219-T81 alloy. The thermal and mechanical history of the panel exceeds -T81 processing, approaching the -T87 sequence.

The fissures had no apparent effect on tensile properties. The low elongation values obtained from the ribbed specimens may be attributed to the stiffening effect of the ribs.

TABLE I

MECHANICAL PROPERTIES OF PANEL SEGMENT

		Ultimate Tensile Strength, psi	Yield Tensile Strength, psi	Per cent Elongation In 2 Inches
Rib Area	1	62,700	45,600	12.5
	2	64,200	46,900	10.5
	Average	63,500	46,300	11.5
1/2 in. Panel Area	1	63,500	47,700	13.0
	2	63,500	47,900	13.0
	3	63,600	48,100	11.0
	Average	63,500	47,900	12.3
1/4 in. Panel Area	1	64,400	47,200	11.0
	2	63,700	47,400	11.0
	3	64,000	46,700	13.0
	Average	64,000	47,100	11.3
1/4 in. Panel Area (With Ribs)	1	63,800	49,400	2.5
	2	63,600	49,400	3.0
	Average	63,700	49,400	2.75

SECTION V. PROCESS POTENTIAL

A. HISTORY

In the development of the S-IV stage for the Saturn vehicle, it was observed that a waffled inner surface in the liquid hydrogen tanks served as anti-slosh baffles. The use of waffled sections eliminated weight taken up by cruciform or other conventional baffles and increased the structural integrity of the tank.

The waffled sections have been made by conventional means, such as chemical or mechanical milling. In material cost alone, the metal loss of nearly 80 per cent is extremely high. The special tooling required is also very expensive. The number of skin mills capable of handling these panels is small, and machinery for milling larger panel sections is virtually non-existant.

The technique of "coining" is ancient. Using this technique unmodified, i.e., developing a full panel in one pass, is virtually impossible in our present state of the art. Assuming a stress of 50,000 psi to extrude aluminum, a press must develop 945,000 tons (excluding friction and work-hardening) to fully form one panel 120 inches wide by 315 inches long.

B. ADVANTAGES OF COLD PRESS-EXTRUSION

By forming the ribs incrementally, the need for extremely large or specialized equipment is eliminated, even for the development of panels for Nova-class vehicles. In this process metal is displaced by a single working punch, concentrating at least 50 per cent of the press force in a single punch face. The metal flow is kept out of worked areas by maintaining punches, and kept from undeveloped areas by holding punches. By indexing the working punch across the panel width, and indexing the panel forward (under the punch head) as each formed row is completed, the press requirements for successful incremental panel forming are:

(1) Sufficient force to extrude one flat area.

(2) Sufficient width to accommodate a full-size panel.

(3) Sufficient room around the press to handle the panel.

The product resulting from this process is superior to the present panels being fabricated by conventional techniques. Primarily, the lines of flow are uninterrupted by machining. This should give improved properties in flexure and fatigue applications. Secondarily, the use of smooth punches ensures a finished surface free of defects such as machine marks which may act as stress-raisers. Figure 16 shows an etched cross-section through a rib located in a thin skin area.

Because this process is extrusion rather than metal removal, there is no material loss required by this manufacturing technique.

C. POSSIBLE INTEGRAL SHAPES

The pilot study has indicated that flat areas of any desired shape may be developed by this technique.

A rib shape that would be desirable is a tee-section rib. After an upright rib is fully developed, special holding dies may be clamped alongside and the tee shape formed by a modified coldheading process.

By extending the lower platen side rails to full rib height (to serve as maintaining punches) and reshaping the faces of the outermost punches, fully developed ribs may be formed at the outside edge of the panel, eliminating the requirements for trimming or dressing the finished panel.

SECTION VI. RECOMMENDATIONS

A. PROCESS DEVELOPMENT

Due to the apparent advantages and unlimited possibilities of the cold press extrusion process, it is recommended that continuation and expansion of this preliminary feasibility study be authorized in the following areas:

1. Punch Development. It is recommended that a study be initiated to determine the effects of punch face contour on metal flow during the extrusion process. A particular emphasis should be placed upon the effects on grain size reduction through working, the avoidance of wave action, and the elimination of voids or pockets.

2. Press Development. It is recommended that a technique be developed for accurate indexing of the work piece within the press for incremental development of a full size panel.

It is also felt that a development program to utilize an impact-type working punch surrounded by holding/maintaining punches may be of great advantage.

3. Alloy Investigation. The feasibility of using alloys other than 2219 for cold press extrusion should be investigated.

4. Warm Extrusion. It is recommended that an investigation be made of spot warming the panel areas just prior to extrusion. This would decrease the yield strength of the panel area and increase the flow of metal into narrow or thin rib areas. This would also decrease the press tonnage required.

5. Theoretical Analysis. It is recommended that the mathematics of cold press extrusion be investigated rigorously. It would appear that the extrusion phenomena are closely analogous to laminar flow in a viscous fluid. By correlation of theoretical results with empirical data, future process requirements and results may be predicted accurately. It is felt that rigorous analysis coupled with, and directing, the other recommended test and development programs should advance the state of the art much more rapidly than a program based on purely empirical data.

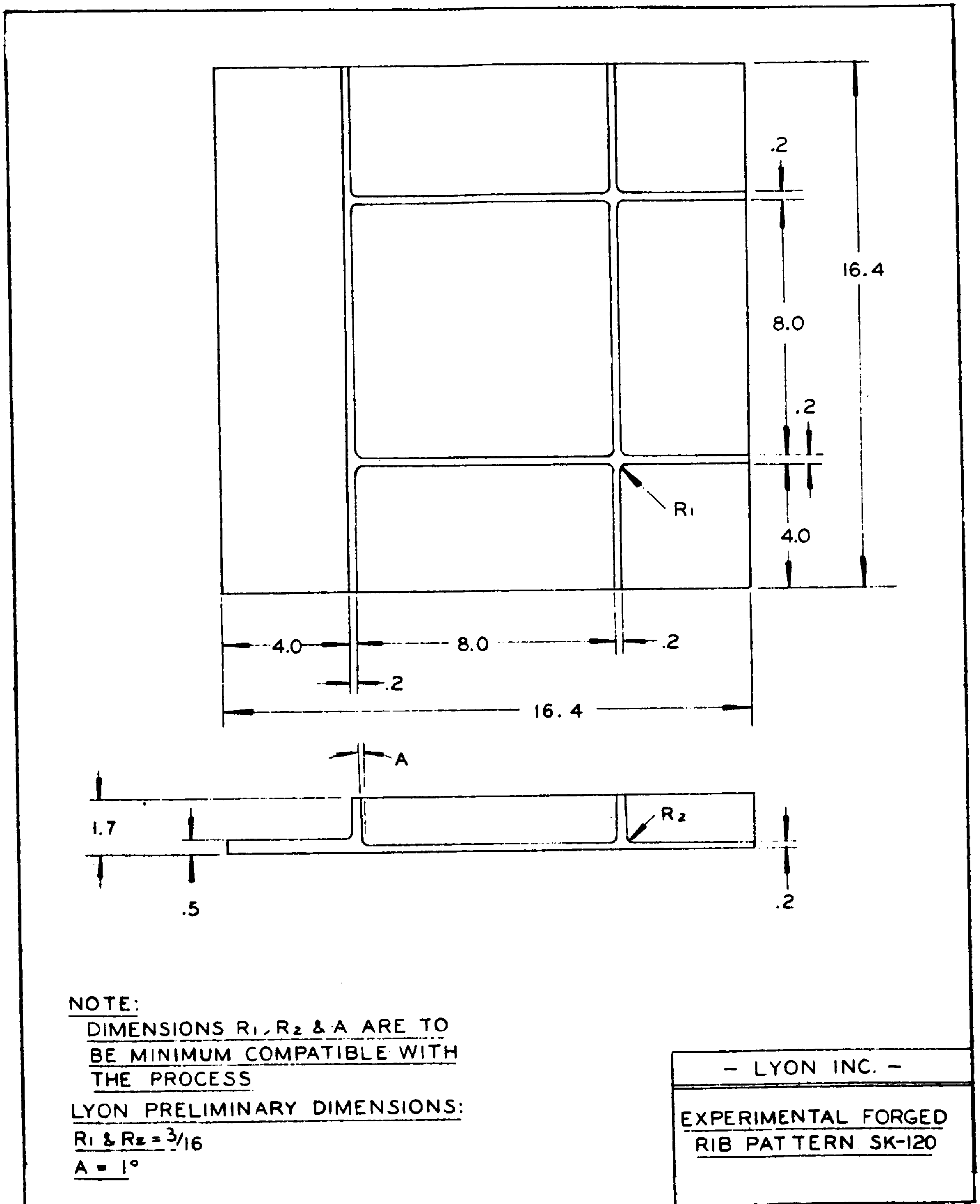

FIGURE 1. MSFC DRAWING SK-120

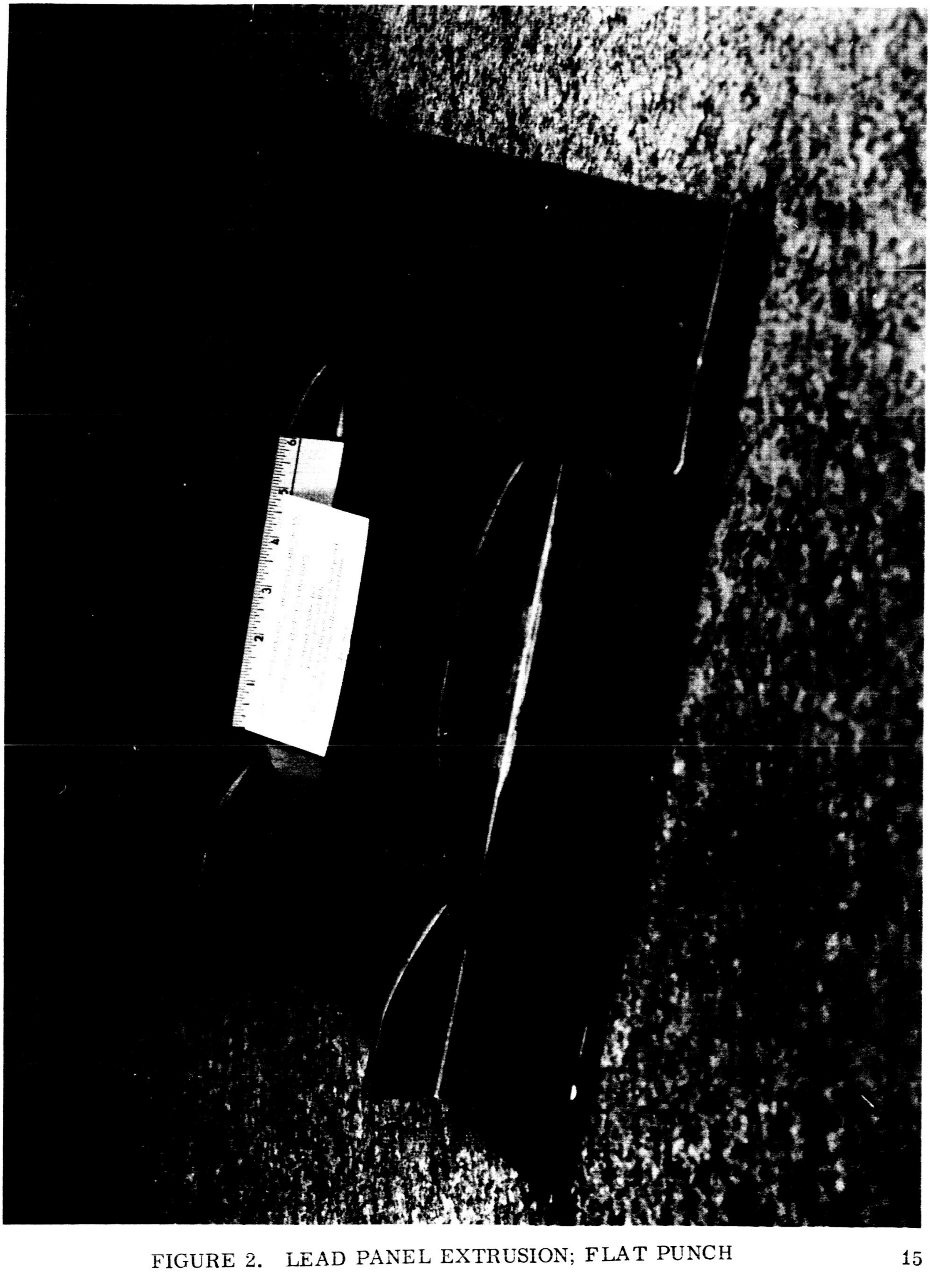

FIGURE 2. LEAD PANEL EXTRUSION; FLAT PUNCH

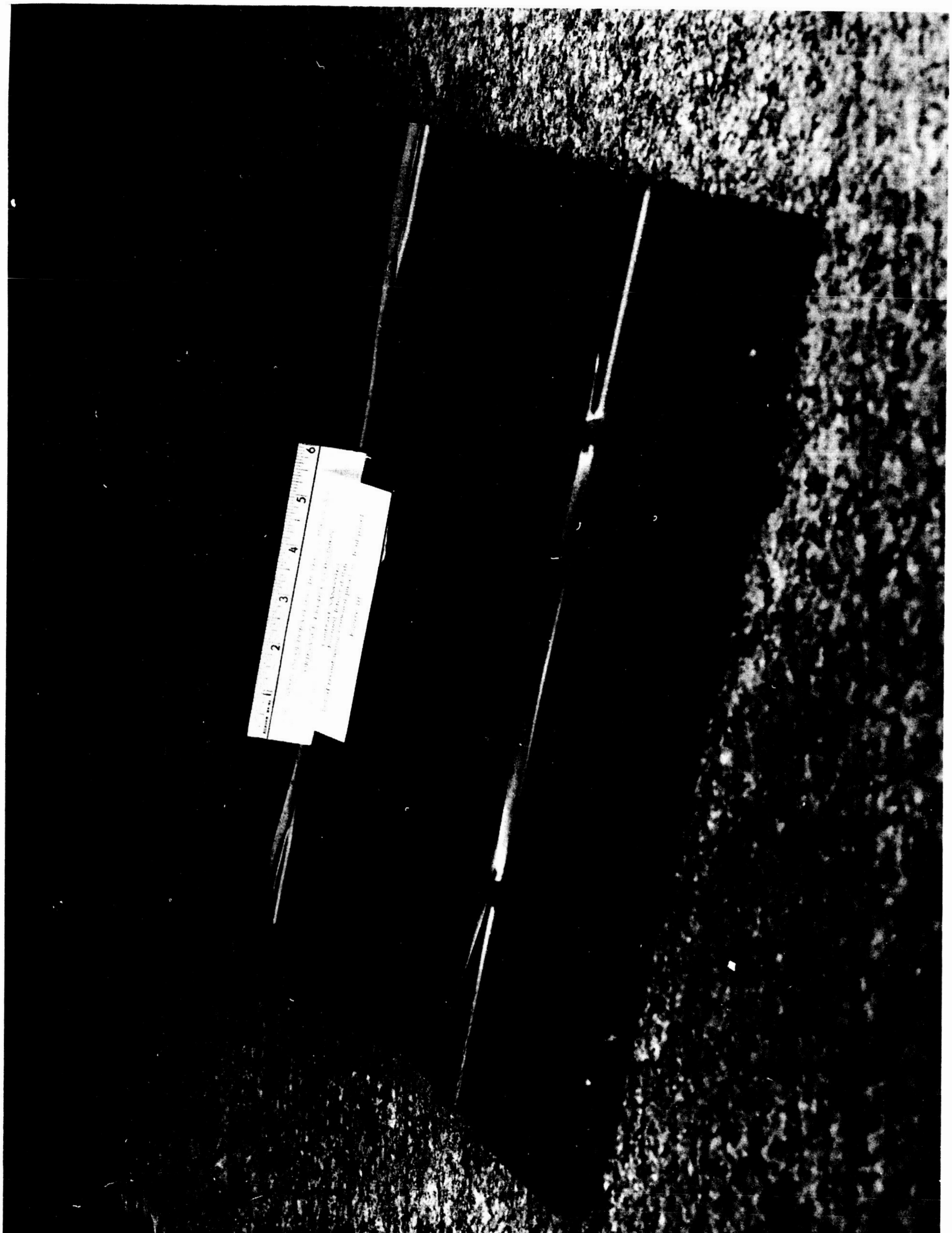

FIGURE 3. TOOLING TEST PANEL; CROWNED PUNCH

FIGURE 4. TOOLING TEST PANEL; FLAT PUNCH

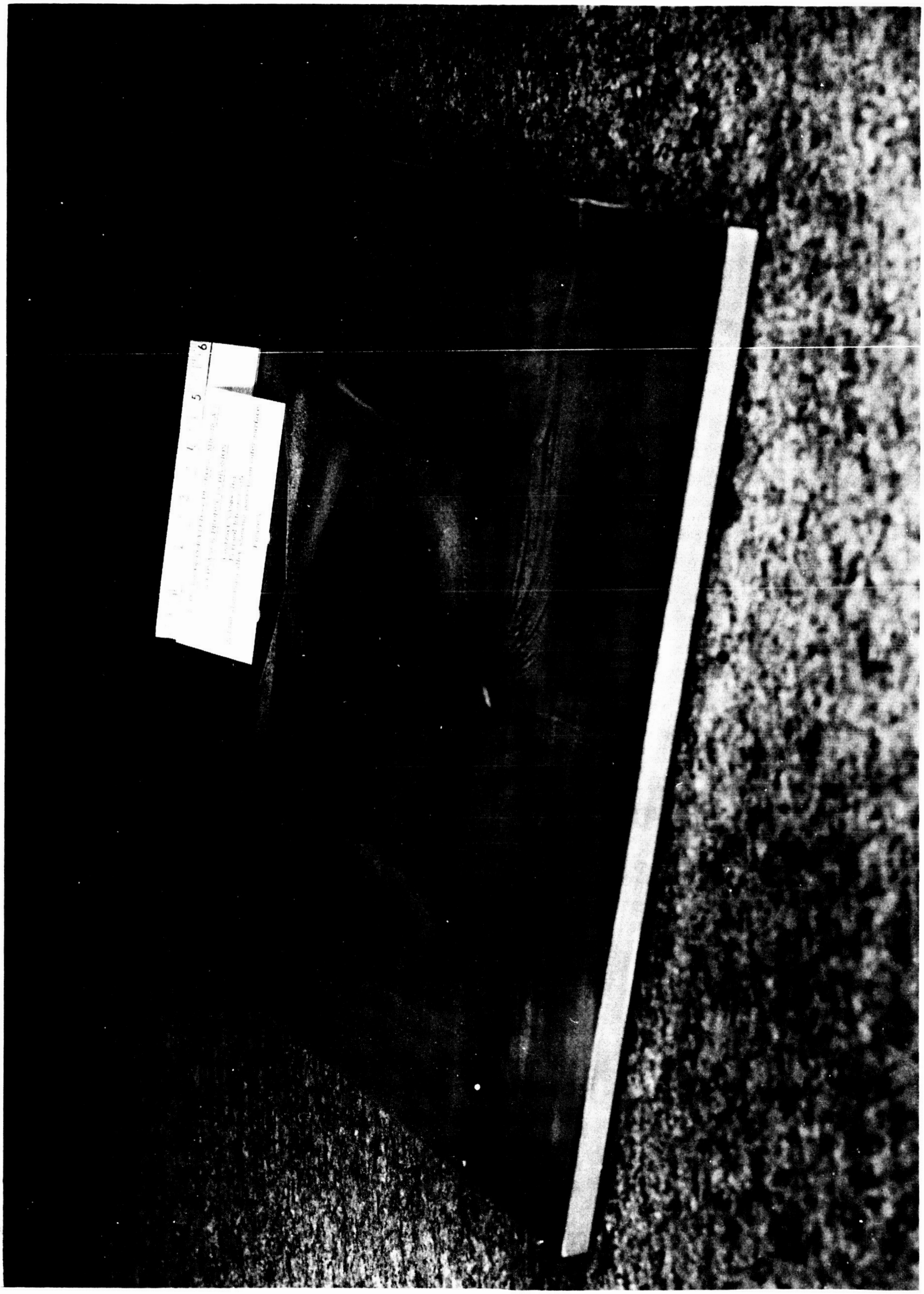

 FIGURE 5. ALLOY PANEL BOTTOM; 6 DEGREE CROWN PUNCH

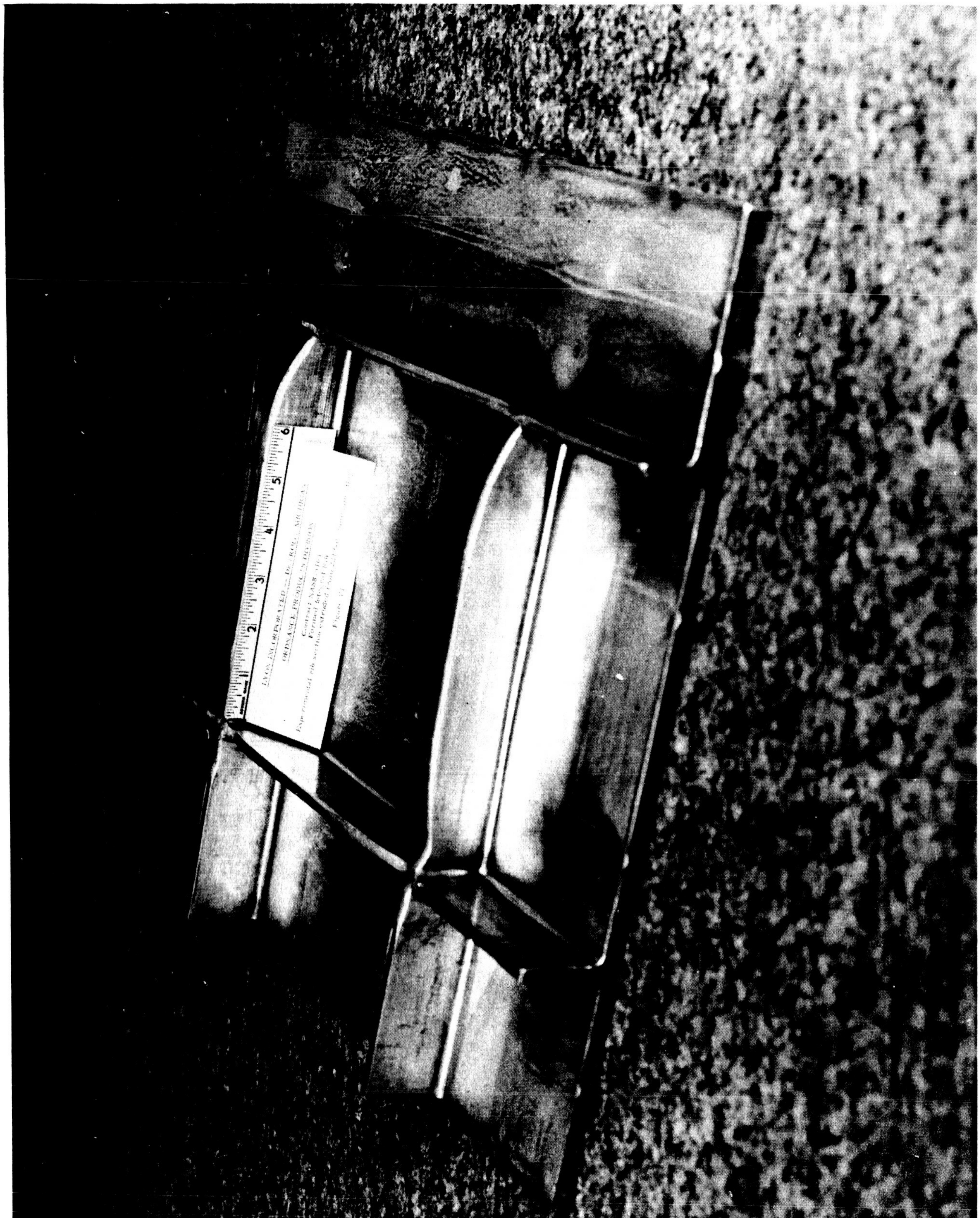

FIGURE 6. ALLOY PANEL; 6 DEGREE/FLAT PUNCH SEQUENCE

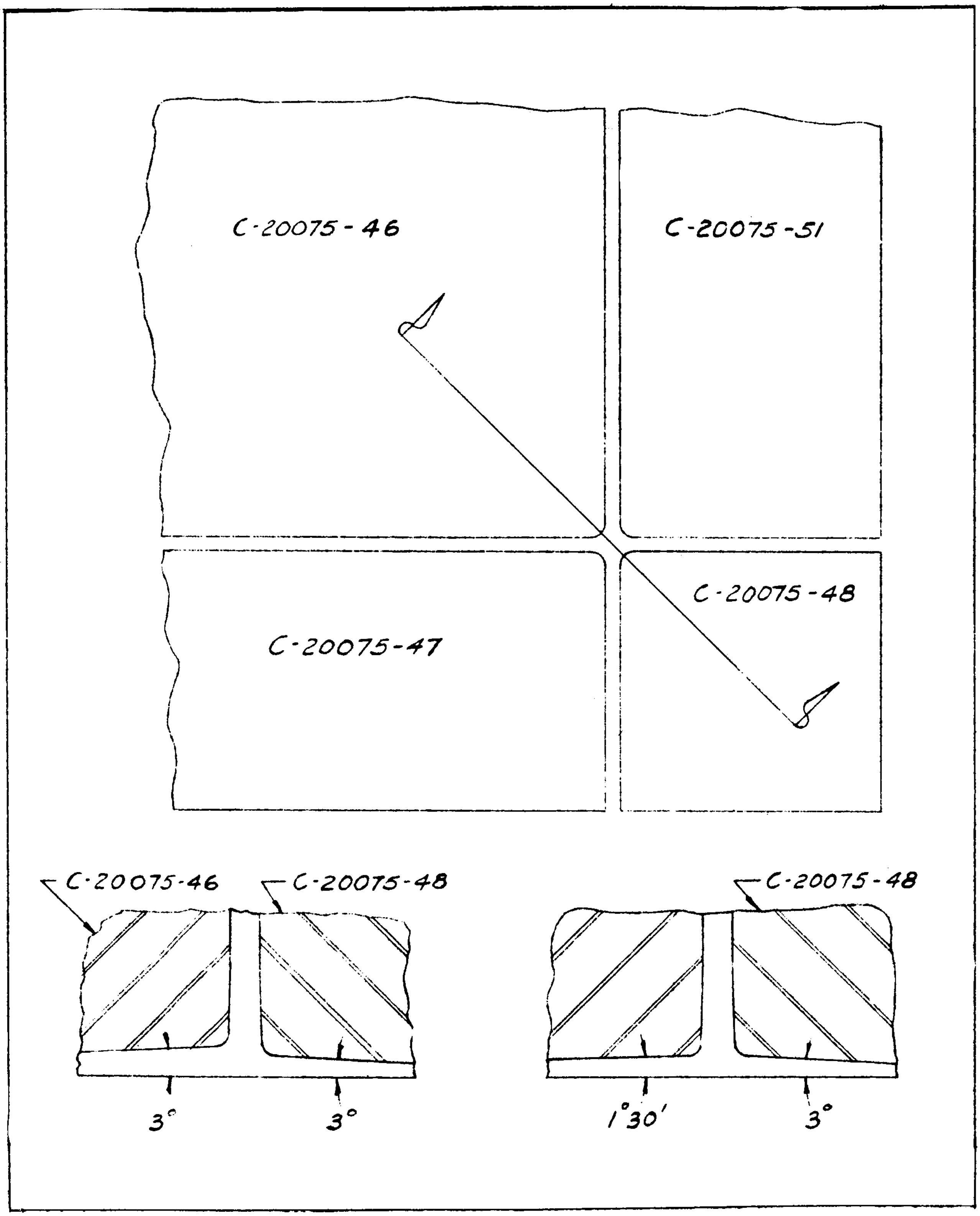

 FIGURE 7. SECTIONS SHOWING 3 DEGREE PUNCHES AND MODIFIED PUNCH

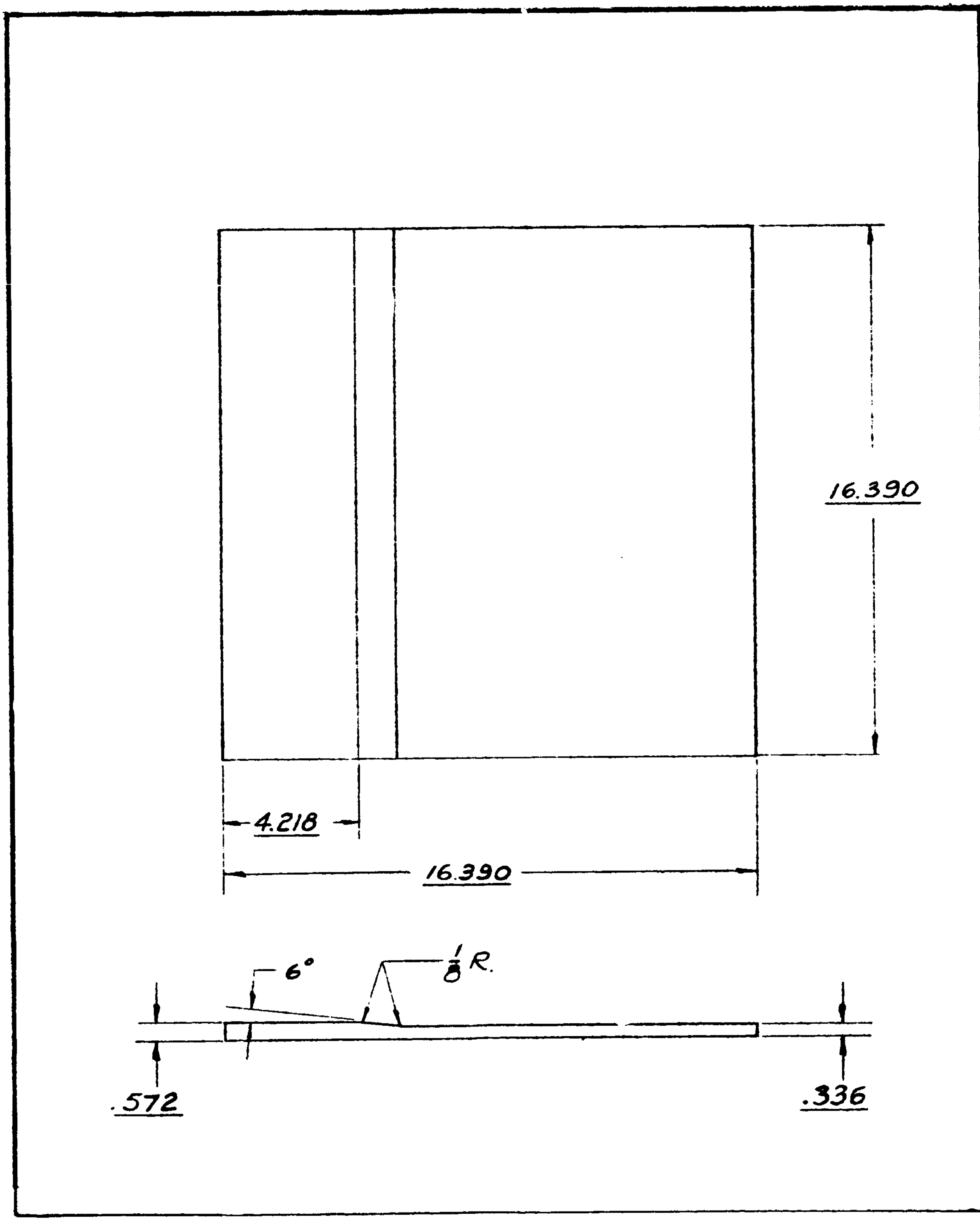

FIGURE 8. DRAWING OF PANEL REDESIGN

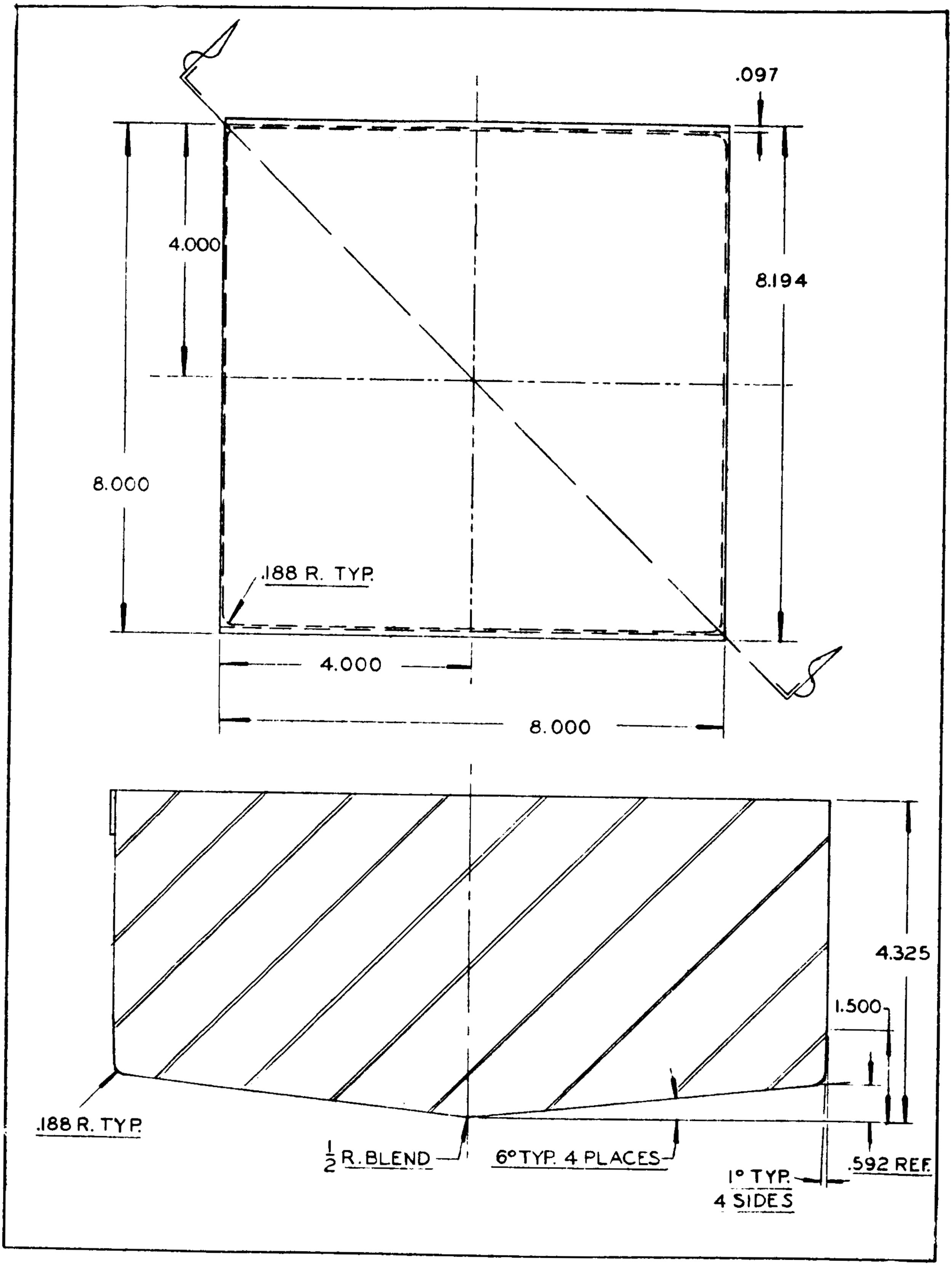

FIGURE 9. CONFIGURATION OF 6 DEGREE PUNCH

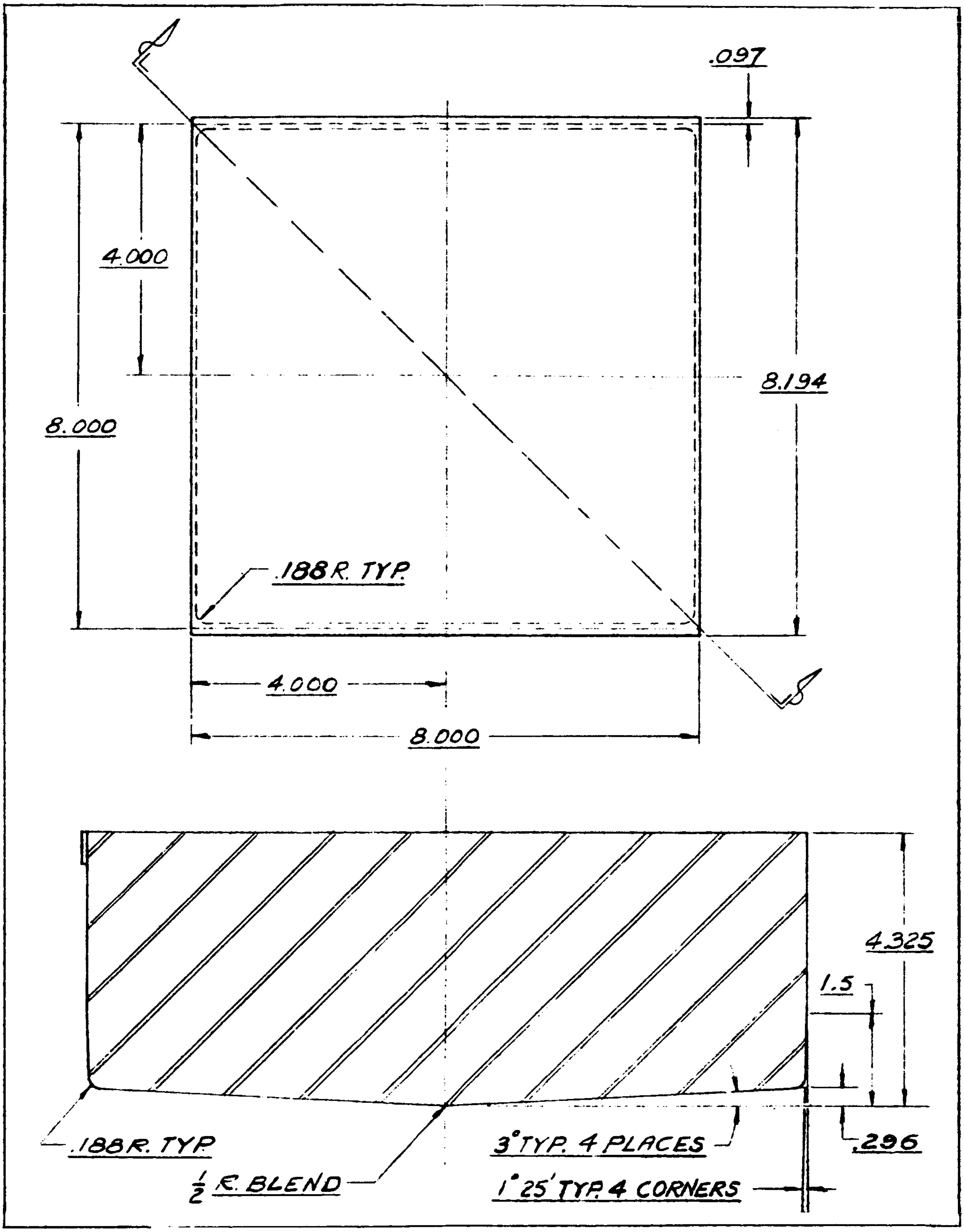

FIGURE 10. CONFIGURATION OF 3 DEGREE PUNCH

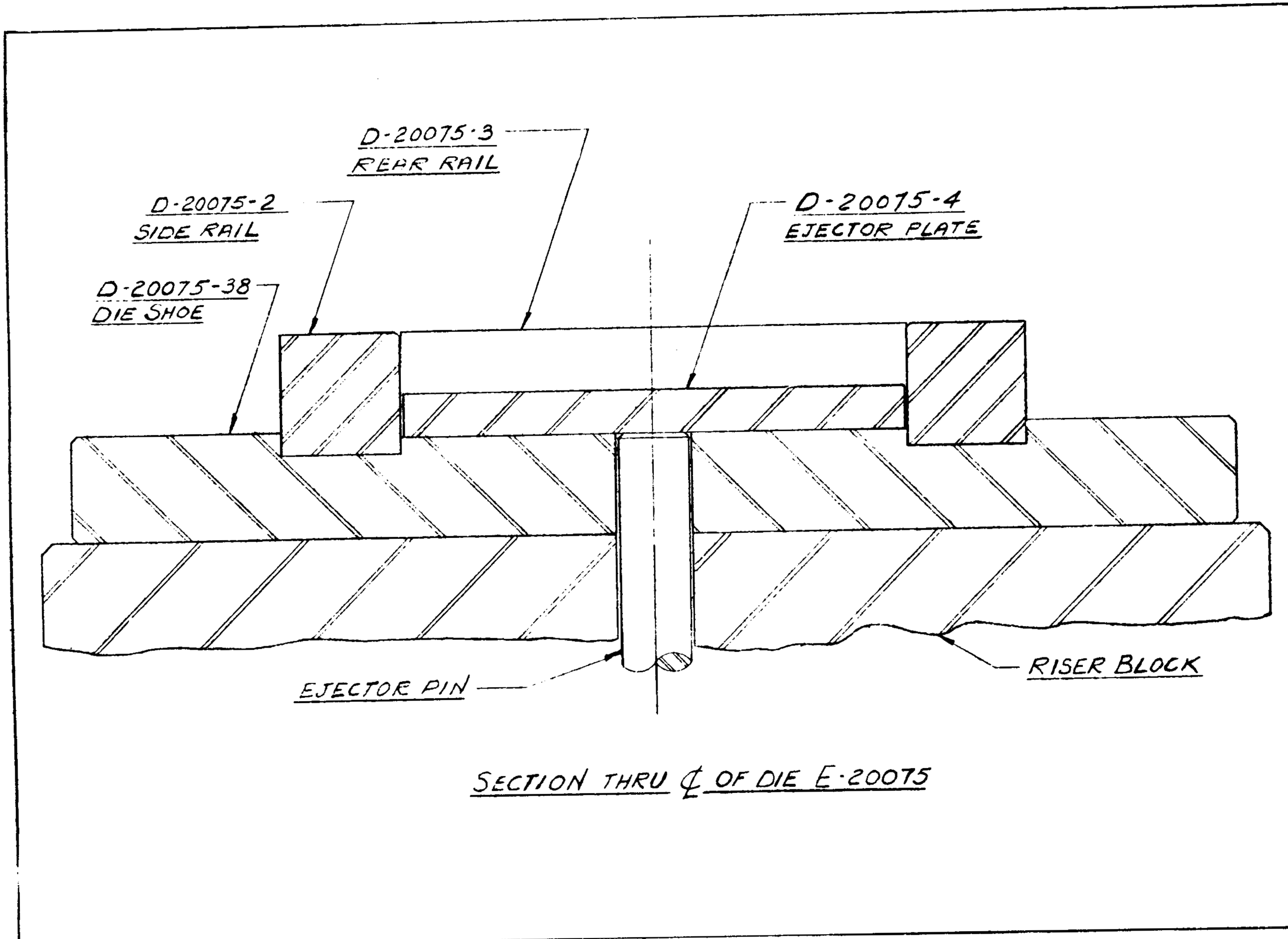

FIGURE 11. DIAGRAM OF LOWER PRESS ASSEMBLY

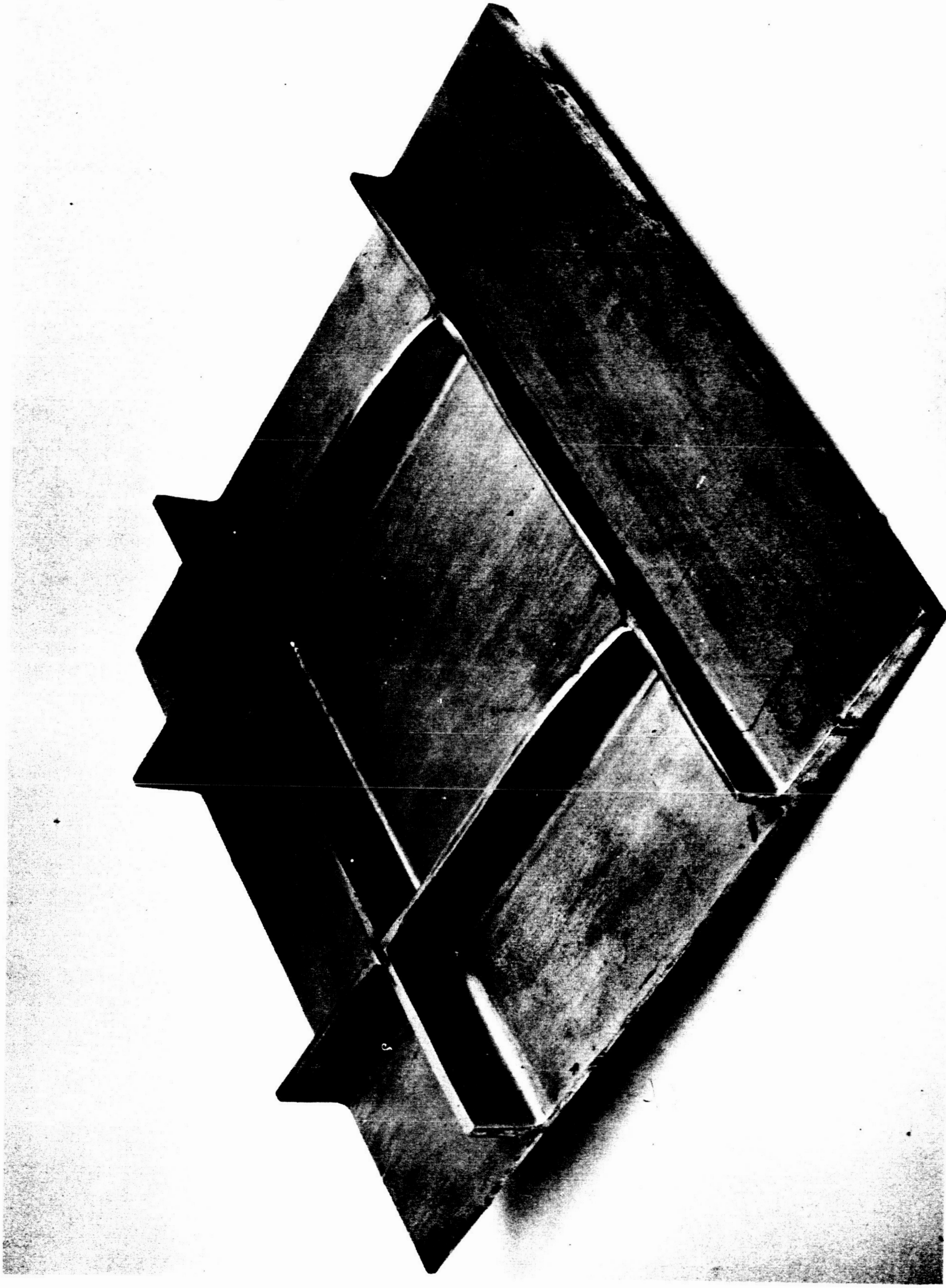

FIGURE 12. DEVELOPED ALLOY PANEL

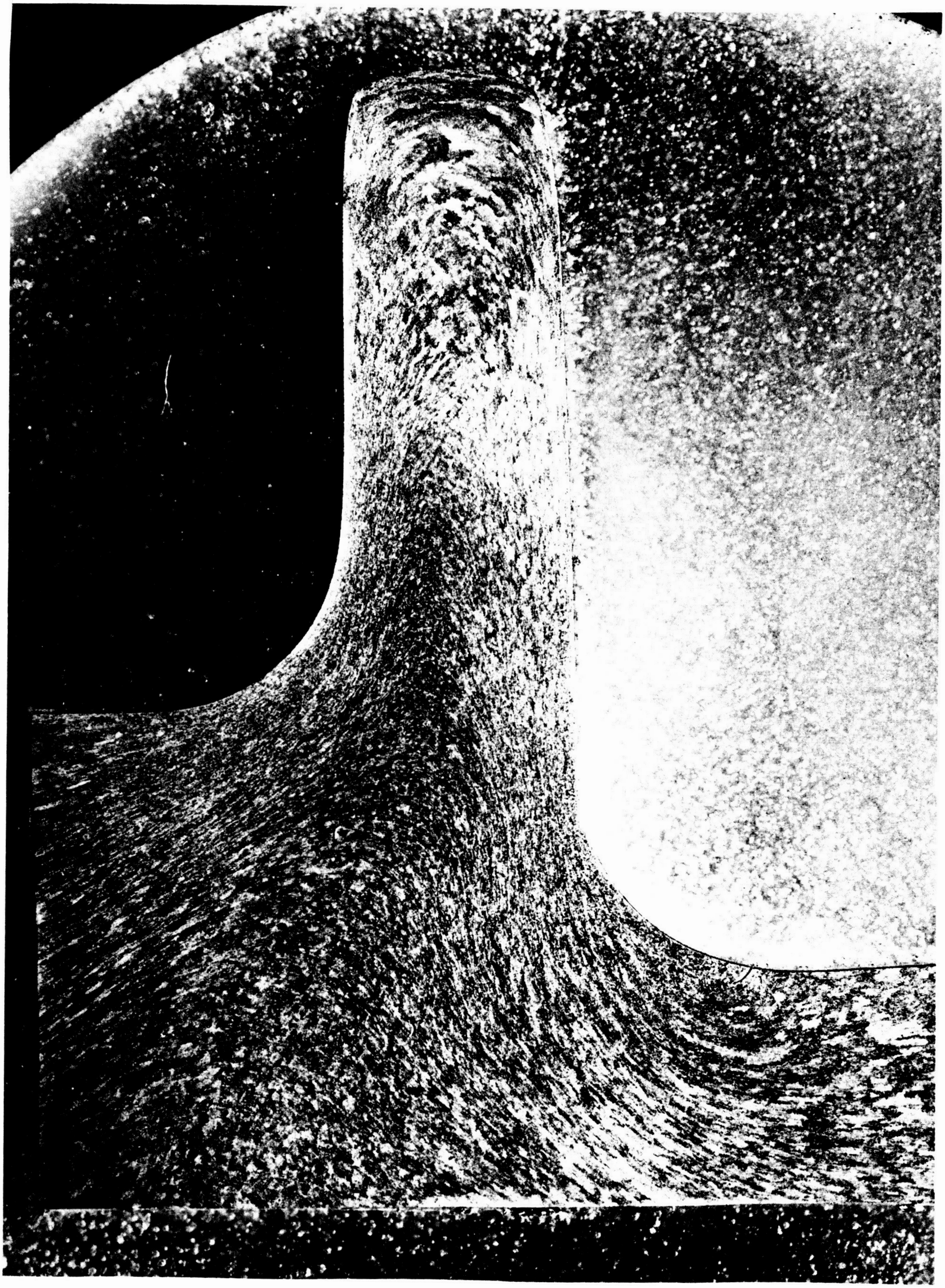

 FIGURE 13. CROSS-SECTION OF LONG RIB; PANEL TRANSITION AREA

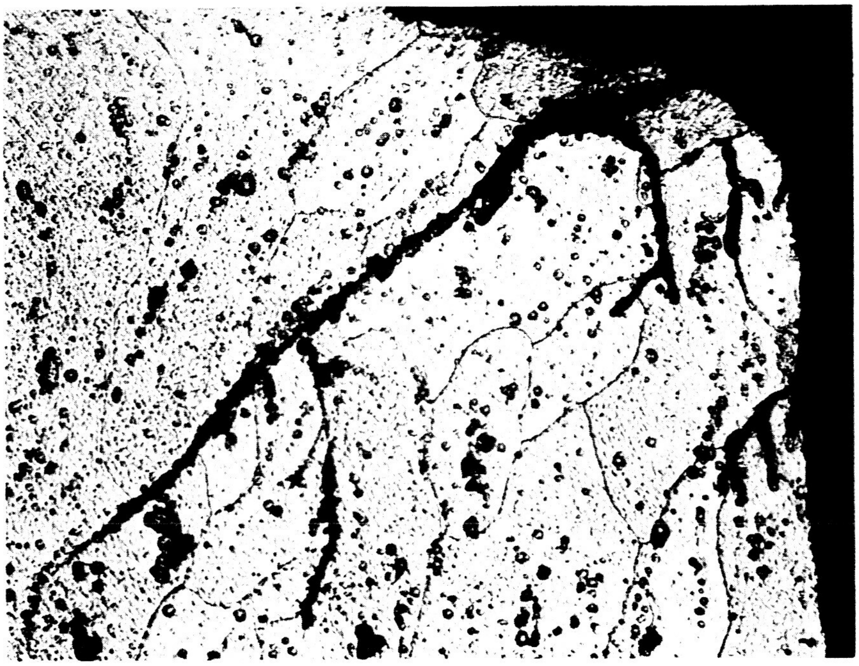

FIGURE 14. 500X OF FISSURE; KELLER'S ETCH

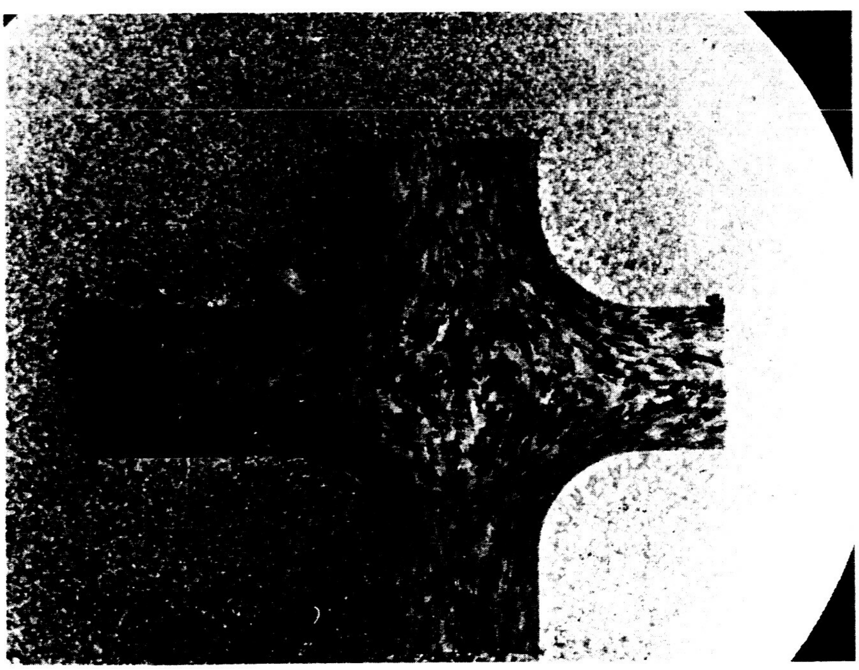

FIGURE 15. CROSS-SECTION OF RIB INTERSECTION

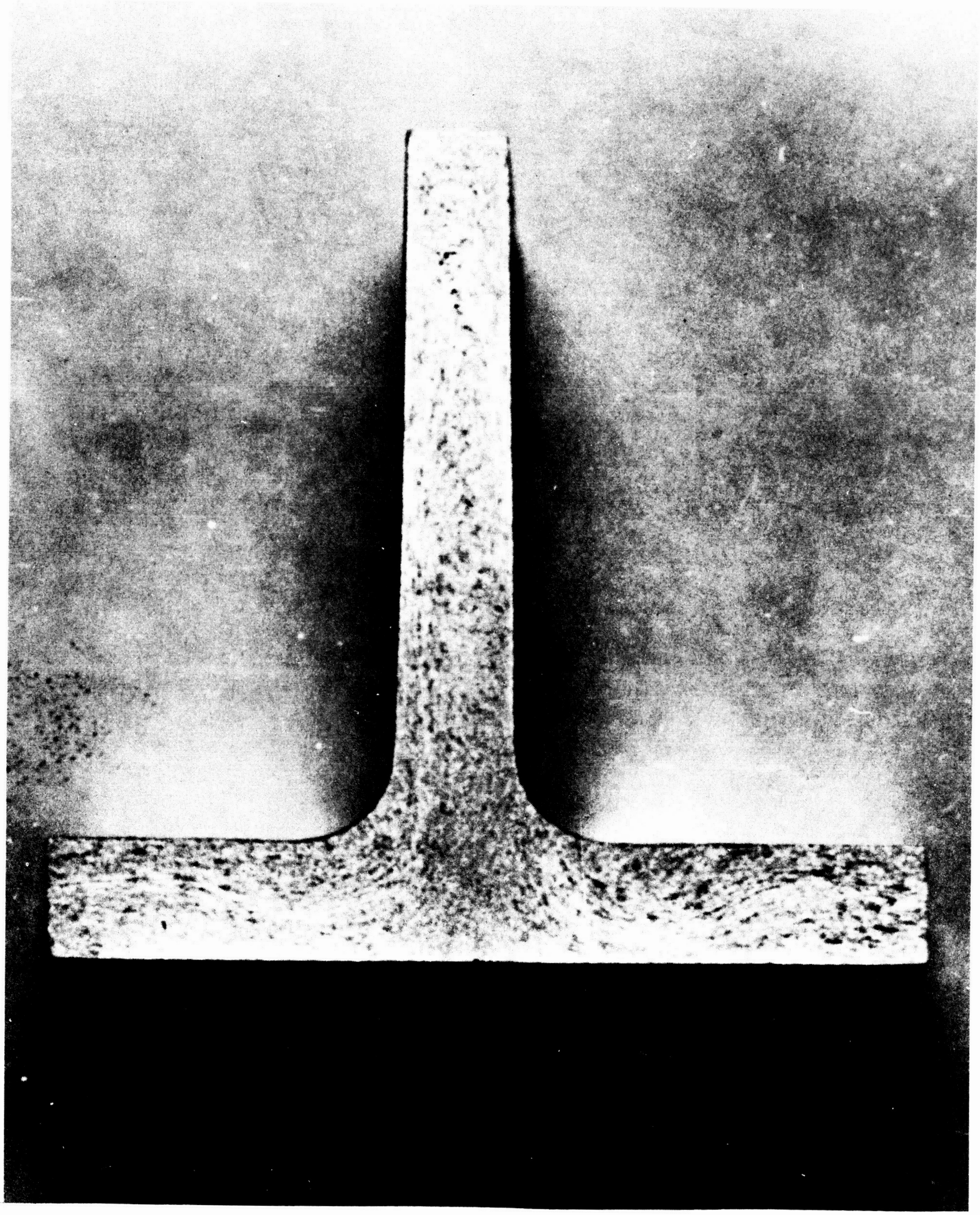

FIGURE 16. CROSS-SECTION OF THIN SKIN-AREA RIB

APPROVAL NASA TM X-53058

FORMING OF INTEGRAL RIBS BY COLD PRESS-EXTRUSION TECHNIQUES

By

P. H. Schuerer
P. R. Bradie

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This report has also been reviewed and approved for technical accuracy.

P. H. Schuerer

P. H. SCHUERER
Author

P. R. Bradie by P.H.

P. R. BRADIE
Author

J. P. Orr

J. P. ORR
Chief, Manufacturing Research and Technology Division

Werner R. Kuers

WERNER R. KUERS
Director, Manufacturing Engineering Laboratory

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